Car Diagnosis Systems

Second-generation systems using the OBD-2 standard interface

by G. Müller

Car diagnosis systems have until now been manufacturer-specific and generally designed so that only authorised garage personnel can gain access to the data. This is now changing with the introduction of the standardised OBD-2 system, which has become an EU standard (EOBD) for all newly-developed cars. In this article we describe the interface in detail, and in a future article we will present a do-it-yourself EOBD diagnosis adapter.

Factors such as improved safety and greater comfort, not to mention environmental friendliness, have made modern vehicles more and more complex. As manufacturers update their ranges ever more frequently, pressures on servicing costs grow, and too little time is available for training of garage personnel, car diagnosis systems are becoming essential in order to guarantee rapid, safe and economical testing, servicing and repairs.

Computers, which have been used in cars for some time now, can also be used to diagnose the various systems and functions they control. In order to protect their authorised garages from those not attached to any particular make of car, each manufacturer has so far developed its own proprietary system. One or two standards have emerged, but only as a result of the effect of cost pressures on the supply industries. This has started to change with the national introduction of environmental legislation.

Although less densely populated, the United States was the first to take steps to reduce air pollution from exhaust gases, and still plays a leading role. In particular, the state of California has been prominent in the field of environmental legislation. For a long time European car manufacturers fought against fitting all their cars with catalytic converters, even though they had long been forced to fit them on cars for the American market. Technological advances, such as more powerful computer systems and the development of suitable sensors, combined with ever more stringent legal requirements on car exhaust gases, have led to a soon-to-be-introduced requirement for a certain proportion of cars in California to be so-called zero-emission vehicles.

Whereas here the state has passed the costs onto the driver through differential taxation for 'dirty' and 'clean' vehicles, in the United States the legislation puts the burden on the manufacturer. Manufacturers have been obliged to arrange the diagnosis systems in the car so that the driver is required to take the car into the garage even when the exhaust gas thresholds are briefly exceeded between regular services or testing. The system is called 'On-Board Diagnosis', abbreviated to OBD. In the event of excessive exhaust gases or failures in the vehicle's safety systems, a yellow 'Check Engine' lamp lights (**Figure 1**). The light is sometimes labelled 'Service Engine Soon' or 'Malfunction Indicator Lamp' (abbreviated MIL). This system has been a requirement in California since 1988, and was adopted by all the other states of America in 1994. In 1996, after further development, it was replaced by the standardised OBD-2 (or OBD-II)

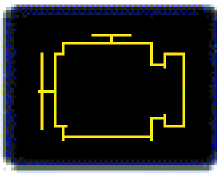


Figure 1. 'Check Engine' lamp symbol (source: author).

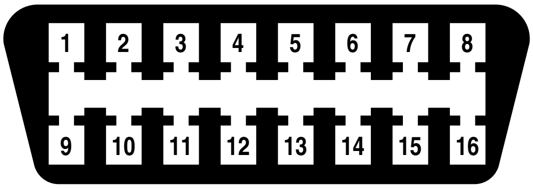


Figure 2. The 16-way diagnosis connector used in OBD-2 (source: author).

system, which is now in widespread use across manufacturers.

In an endeavour to encourage open competition, as well as in the interests of environmental protection, the European Union has issued guidelines (98/69/EU, dated 13/10/1998 [1]) for further reduction in exhaust gas levels requiring the installation of on-board diagnosis systems by all manufacturers according to the American standards. Manufacturers will be obliged for the first time to fit standardised diagnosis interfaces and connectors to allow the connection of suitable diagnosis equipment. Manufacturers will also be forced to publish details of significant parts of their diagnosis systems, which have until now been proprietary. The EU guidelines apply to spark-ignition engines (i.e., petrol engines) registered in 2000 and after, and to self-ignition engines (i.e., diesel engines) registered in 2003 and after.

OBD-2 diagnosis connector

The requirements stipulate that the diagnosis connector for OBD-2, or EOBD (European On-Board Diagnosis system), must be situated in the passenger compartment near the driver's seat. This is in contrast to previous systems where the connector has been in the engine compartment. Usually the connector will be below the instrument panel or in the central console, sometimes covered by a flap, sometimes behind the ashtray.

OBD-2 employs a 16-way connector (**Figure 2**), although not all the ways are fitted with pins (see **Table 1**).

Table 2 shows the various protocols of the bus system. It will be clear that there is little agreement between manufacturers. Among the American companies, Ford use a PWM (pulse width modulation) protocol and General Motors use a VPW (variable pulse width modulation) protocol, both to the SAE J1850 standard, while the European and Far Eastern manufacturers generally use the KWP (key word protocol) according to ISO 9141-2.

Significance

What does the new diagnosis system mean for the driver? Whereas previously most of the intelligence

Table 1

Standardised pins on the OBD-2 connector

Pin 2	J-1850 bus +
Pin 4	Chassis ground
Pin 5	Signal ground
Pin 6	CAN high (J-2284)
Pin 7	ISO 9141-2 K output
Pin 10	J-1850 bus
Pin 14	CAN low (J-2284)
Pin 15	ISO 9141-2 L output
Pin 16	Battery positive

Table 2

Real-time data readable in mode 01 (not all data is available on all vehicles):

Fuel system 1 and 2 status
Calculated load value
Engine coolant temperature
Short-term fuel-air mixture proportion bank 1
Long-term fuel-air mixture proportion bank 1
Short-term fuel-air mixture proportion bank 2
Long-term fuel-air mixture proportion bank 2
Fuel pressure (measured)
Inlet pressure
Engine speed
Road speed
Ignition timing advance for cylinder 1
Inlet air temperature
Mass air flow (MAF) sensor reading
Absolute throttle valve position
Commanded secondary air status
Installed Lambda probe locations, where probe 1 is nearest engine
Bank 1 sensor 1 Lambda probe reading and calculated short-term fuel-air mixture proportion
Bank 1 sensor 2 Lambda probe reading and calculated short-term fuel-air mixture proportion
Bank 1 sensor 3 Lambda probe reading and calculated short-term fuel-air mixture proportion
Bank 1 sensor 4 Lambda probe reading and calculated short-term fuel-air mixture proportion
Bank 2 sensor 1 Lambda probe reading and calculated short-term fuel-air mixture proportion
Bank 2 sensor 2 Lambda probe reading and calculated short-term fuel-air mixture proportion
Bank 2 sensor 3 Lambda probe reading and calculated short-term fuel-air mixture proportion
Bank 2 sensor 4 Lambda probe reading and calculated short-term fuel-air mixture proportion
OBD requirements, model dependent
Auxiliary input status

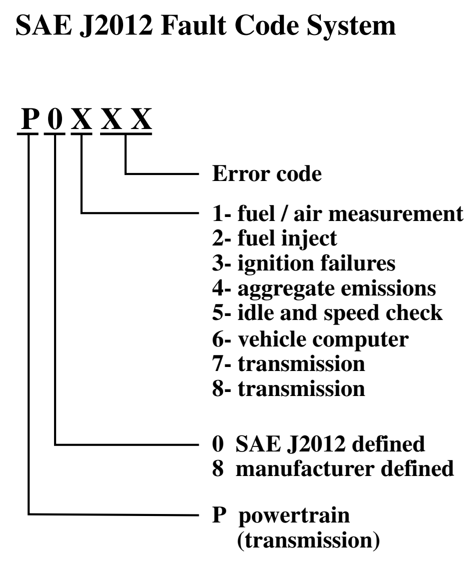


Figure 3. Fault codes according to SAE 2012 (source: author).

resided in the computer in the garage connected to the diagnosis system, this is now being transferred to the ever-more-powerful on-board computer. This means that an economical read-out device is all that is required to find the exact location of a fault in the car's systems. This does not help the ordinary driver, since in general he will not be able to sort out the problem on his own. However, it does mean that he will perhaps be able to drive to the nearest small garage or workshop instead of first making an appointment at an authorised repair shop, which might not always be feasible on a long holiday journey, for example. At least he can be spared to worry of not knowing what the illuminated service lamp means: all the manual will say is 'drive to the nearest repair shop'.

Fault conditions

When and why do the fault indicator lamps light? Along with the other indicator lamps, the Malfunction Indicator Lamp (henceforth MIL) lights when the ignition key is turned and go out when the engine starts: this tests that the lamps themselves are working. If the lamp lights, and stays on, during a journey, then a fault is indicated. If the lamp flashes during a journey it indicates that the engine electronics have detected a misfiring, which can lead to the catalyst being damaged by incompletely burnt fuel-air mixture reaching the exhaust. The two MIL signals generally mean that the engine electronics has switched to an emergency mode to try to prevent damage to the engine. For example, if the Lambda probes detect too lean a mixture, serious damage to the engine can result. The emergency mode will at least allow a safe journey as far as the next garage and should prevent further damage. With the on-board facilities nothing more is possible: in contrast, the first-generation on-board diagnosis systems could be made to elicit the display of a fault number by bridging two pins of the diagnosis connector, or by pressing a button on the central console; but this is no longer possible with OBD-2.

Figure 4. Typical handheld device for reading out fault codes (source: Actron Manufacturing Company, Cleveland, Ohio).

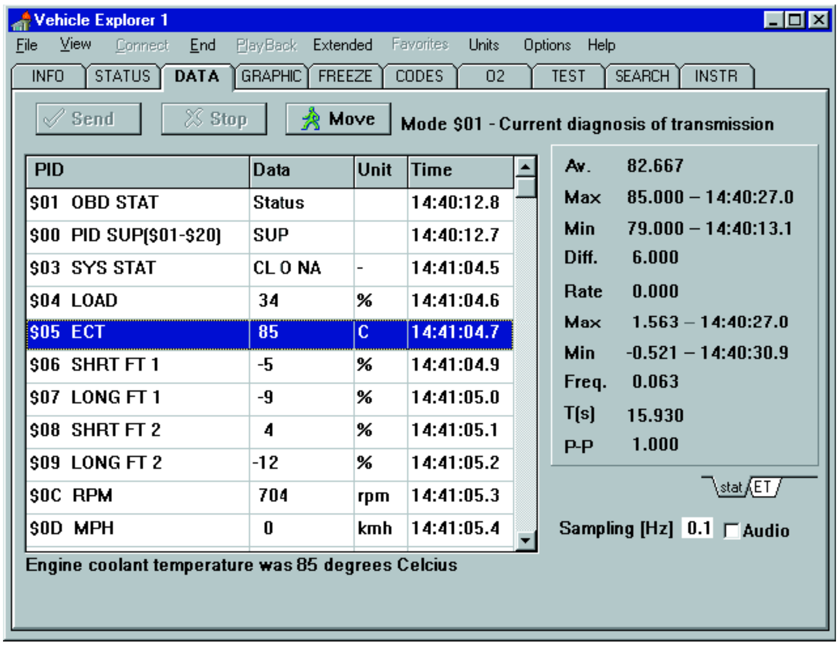
With luck, the MIL will suddenly extinguish after driving a little further. The standard stipulates that intermittent faults, which do not recur within a preset number of journeys, shall not light (or shall reset) the MIL. Nevertheless, a block of data is stored in the system containing all the data from the important sensors at the moment when the fault is detected: a so-called 'freeze frame'. This freeze-frame data can be read out at the next service to give an indication as to the cause of the problem, even when the fault has not recurred for some time. It may be the case that the fault only occurs occasionally or only under specific engine load conditions.

Fault codes

The format of the five-character fault codes specified by SAE J2012 and ISO DIM 15031-6 is shown in **Figure 3**. The OBD-2 standard defines the particular meanings shown for those fault codes that cause the MIL to light. As well as the initial letter 'P' for 'Powertrain' we can also have 'B' for 'Body', 'C' for 'Chassis' and 'U' for network faults. If the second character is '0' then we have a standard fault code. The digits '1' and '2' are used for manufacturer-defined fault codes, within which the manufacturer must adhere strictly to the provisions of the standard. The digit '3' is reserved for future expansion of the standard. The third character defines the system being monitored according to the scheme given in **Figure 3**. Finally, the last two characters give information about the fault: plain text explanations corresponding to these numbers can be looked up in the standard. So, for example, the code 'P0133' indicates that Lambda probe sensor 1 in bank 1 is responding too slowly.

Reading data out

How can we go about reading data out of the system? As we have already seen in **Table 2**, not only are there three different communications protocols that might be available on the OBD-2 connector according to the vehicle manufacturer, but we also have the problem that none of


Vehicle Explorer 1
File View Connect End PlayBack Extended Favorites Units Options Help
INFO STATUS DATA GRAPHIC FREEZE CODES 02 TEST SEARCH INSTR
Send Stop Move
stat ET
Audio

Mode $01 - Current diagnosis of transmission

PID	Data	Unit	Time
$01 OBD STAT	Status		14:40:12.8
$00 PID SUP($01-$20)	SUP		14:40:12.7
$03 SYS STAT	CL O NA	-	14:41:04.5
$04 LOAD	34	%	14:41:04.6
$05 ECT	85	C	14:41:04.7
$06 SHRT FT 1	-5	%	14:41:04.9
$07 LONG FT 1	-9	%	14:41:05.0
$08 SHRT FT 2	4	%	14:41:05.1
$09 LONG FT 2	-12	%	14:41:05.2
$0C RPM	704	rpm	14:41:05.3
$0D MPH	0	kmh	14:41:05.4

Av.	82.667
Max	85.000 – 14:40:27.0
Min	79.000 – 14:40:13.1
Diff.	6.000
Rate	0.000
Max	1.563 – 14:40:27.0
Min	-0.521 – 14:40:30.9
Freq.	0.063
T(s)	15.930
P-P	1.000

Sampling [Hz] 0.1

Engine coolant temperature was 85 degrees Celcius

Figure 5. It is possible to use a dedicated program such as ‘Vehicle Explorer’ to read fault codes out using a PC.

these protocols is compatible with protocols commonly found on computers, such as the handshake protocol of the serial interface.

As well as the expensive analysis equipment that vehicle manufacturers supply to their authorised repair shops, an increasing number of economical devices is becoming available from third party suppliers. These are either self-contained handheld devices which are generally only capable of reading out the fault codes, or consist of an adapter cable which offers many more facilities via dedicated PC-based software. The OBD-2 connector has much more to offer than just fault codes.

A representative example of the handheld type of equipment is the Kal KM9040 (**Figure 4**). As with most devices in this category, it is also capable of erasing fault codes from the car’s computer. Prices in this category range from around three hundred to fifteen hundred pounds.

PC-based software solutions (**Figure 5**), employing an adapter cable (**Figure 6**) are also available for palmtop computers. Low-cost systems are available from around one hundred pounds. It is thus within most people’s means to poke around inside their car’s computer. The PC-based solutions generally offer access to the full range of data available from the OBD-2 connector. According to the standard, the system operates in nine modes:

01 gives real-time data
02 gives so-called ‘freeze frame’ data
03 gives fault codes
04 erases fault codes and stored values
05 gives the results of the Lambda probes self-test
06 gives the self-test results of systems that are not continuously monitored
07 gives the self-test results of systems that are continuously monitored
08 dedicated control mode
09 vehicle data request: information such as software version and VIN (vehicle identification number)

Not every vehicle supports every mode. Within each mode the vehicle computer provides a parameter identification (PID) as a hexadecimal number. For example, sending the byte sequence 01 00 asks which requests the vehicle computer can respond to and which data can be provided. After the mode has been selected, in this case 01, PID 00 will determine which further commands are understood in this mode and will be replied to.

We are now already in the middle of the details of the protocol, which are not important to the user of ready-made software products. The relatively simple format of the OBD-2 protocol, as we have illustrated, does however mean that it is possible for a programmer with a little experience to write a suitable program himself. All that is needed is for the OBD-2 communication protocol (41.6 kHz in the case of PWM, 10.4 kHz for VPW and ISO 9141) to be translated into a format suitable for the serial interface of a PC. Suitable ready-made adapter cables are also available, as are pre-programmed microcontrollers (for example from the PIC family) which allow do-it-yourself construction of an

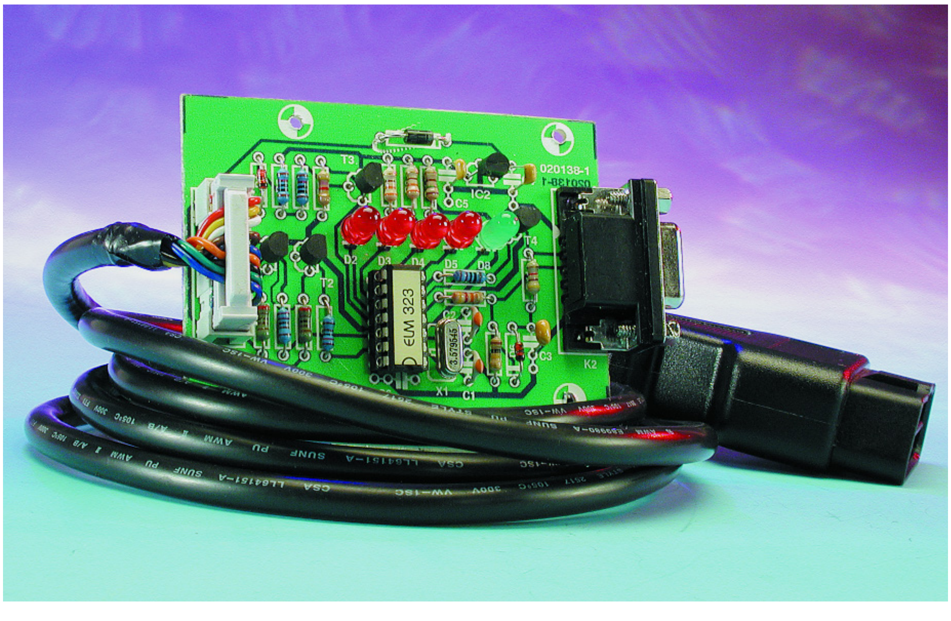


Figure 6. To use the PC-based software a suitable hardware adapter cable is required, which includes a microcontroller to convert between the two interfaces (source: Onboard Diagnostics).

adapter with a simple additional circuit (**Figure 7**). We will be describing such a project in an article in the near future.

Is it worth it?

Anyone who has been through the expensive process of having a new Lambda probe fitted might wonder whether the problem was really the probe or just a loose connection. Almost every garage survey — whether carried out by a motoring organisation or one of the many specialist magazines — has found that complete sensor systems have been replaced when the problem was just a simple, obvious cable fault. A diagnosis tool can thus pay for itself quickly.

Table 3 shows the real-time data that can be read in mode 01. Not all values are available on all vehicles: for example, not all vehicles have four Lambda probes. The calculated load value is not the power directly available from the engine, but rather a dimensionless quantity calculated as the instantaneous air flow rate divided by the maximum air flow rate corrected for altitude. The values can be continuously stored on a laptop and subsequently played back. PC software can present the data visually as graphs (**Figure 8**) or as instrument readings. Sometimes it is possible to set triggers which cause data recording to start or stop when certain values go above or below set thresholds. Usually the freeze-frame data block referred to above (mode 02) will store the same information.

In mode 04 a fault code that has occurred can be cleared. This is to be done with caution, since the operation will also clear the so-called calibration data from the vehicle's computer. Calibration data is information gathered by the vehicle's computer system itself to compensate for component tolerances in the sensors as well as production variations and wear in the engine. If these data values are cleared they will automatically be regenerated over the next journeys. This means that the car should not be taken for its MOT immediately after clearing the fault code and hence also the calibration data.

Finally a brief word to anyone hoping to tune the vehicle computer to get more power out of their car. The EU guideline states that manufacturers should take steps to ensure that 'reprogrammable computer codes or operating parameters should be protected against unauthorised access'. This is generally done using cryptographic processing and encapsulation of the relevant chips in the engine electronics. PC-based OBD-2 systems do not include cryptographic processing.

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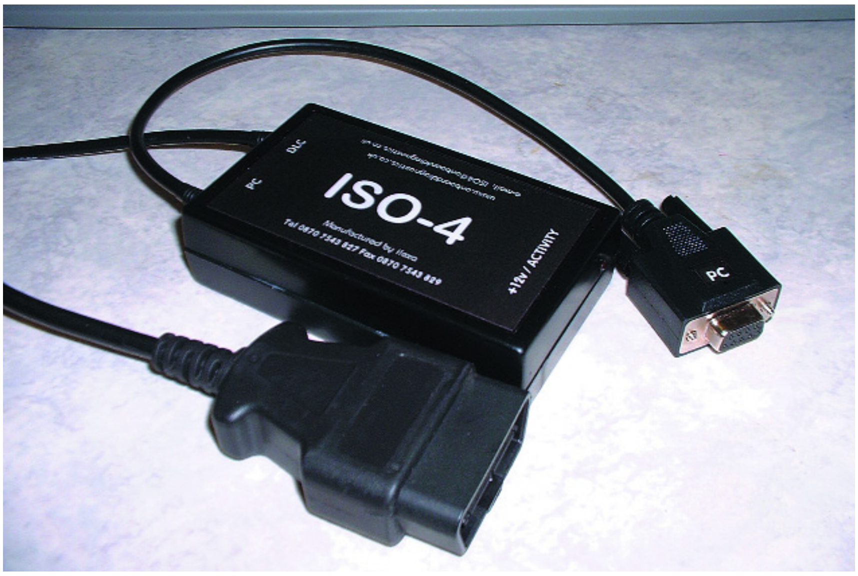

Figure 7. Elektor version of an OBD-2-to-RS232 converter. This design employs a PIC microcontroller.

References and Web links:

[1] EU Guidelines EC70/220, EC98/69, EC99/102, ECE R83
http://europa.eu.int/index_de.htm

[2] ISO and SAE standards
www.beuth.de

[3] Third-party OBD-2 diagnosis equipment suppliers

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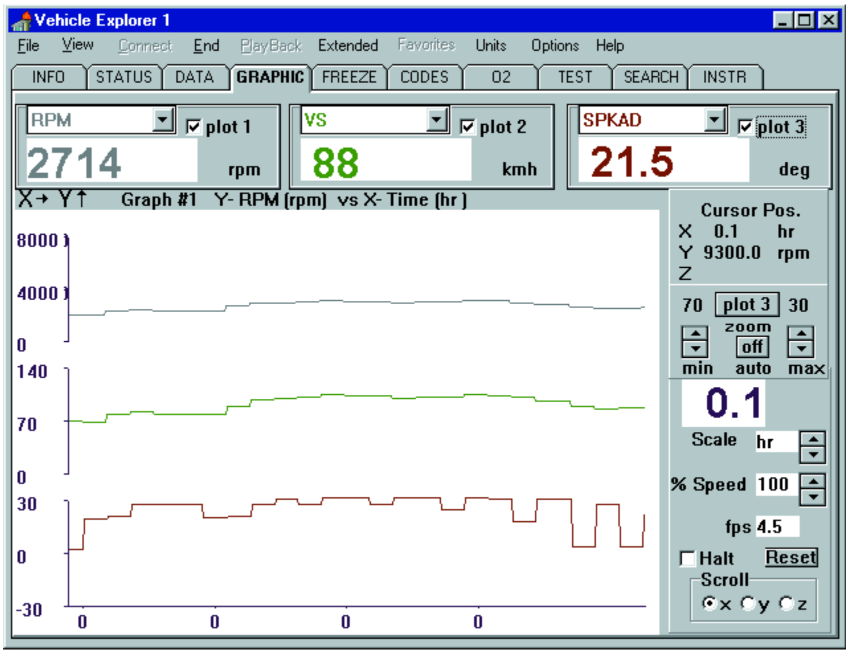

RPM ☑ plot 1 2714 rpm
VS ☑ plot 2 88 kmh
SPKAD ☑ plot 3 21.5 deg
Graph #1 Y- RPM (rpm) vs X- Time (hr)
Cursor Pos.
X 0.1 hr
Y 9300.0 rpm
Z
70 plot 3 30
off
0.1
Scale hr
% Speed 100
fps 4.5
☐ Halt
● x ○ y ○ z

Figure 8. The PC-based programs can present the data visually as charts or as an instrument display.